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Search for Higgs boson decays into pairs of light (pseudo)scalar particles in the $\gamma \gamma jj$ final state in $pp$ collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

The ATLAS Collaboration*

**A R T I C L E I N F O**

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**A B S T R A C T**

This Letter presents a search for exotic decays of the Higgs boson to a pair of new (pseudo)scalar particles, $H \rightarrow a a$, where the $a$ particle has a mass in the range $20–60$ GeV, and where one of the $a$ bosons decays into a pair of photons and the other to a pair of gluons. The search is performed in event samples enhanced in vector-boson fusion Higgs boson production by requiring two jets with large invariant mass in addition to the Higgs boson candidate decay products. The analysis is based on the full dataset of $pp$ collisions at $\sqrt{s} = 13$ TeV recorded in 2015 and 2016 with the ATLAS detector at the CERN Large Hadron Collider, corresponding to an integrated luminosity of 36.7 fb$^{-1}$. The data are in agreement with the Standard Model predictions and an upper limit at the 95% confidence level is placed on the production cross section times the branching ratio for the decay $H \rightarrow aa \rightarrow \gamma \gamma gg$. This limit ranges from 3.1 pb to 9.0 pb depending on the mass of the $a$ boson.

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1. Introduction

The discovery or exclusion of the Standard Model (SM) Higgs boson was one of the main goals of the Large Hadron Collider (LHC) physics programme. A Higgs boson with mass of 125 GeV, and with properties compatible with those expected for the SM Higgs boson ($H$), was discovered by the ATLAS [1] and CMS [2] collaborations. Since its discovery, a comprehensive programme of measurements of the properties of this particle has been underway. These measurements could uncover deviations from branching ratios predicted by the SM or set a limit on the possible branching ratio for decays into new particles beyond the SM (BSM). Existing measurements constrain the branching ratio for such decays ($B_{BSM}$) to less than 34% at 95% confidence level (CL) [3], assuming that the absolute couplings to vector bosons are smaller than or equal to the SM ones.

Many BSM models predict exotic decays of the Higgs boson [4]. One possibility is that the Higgs boson decays into a pair of new (pseudo)scalar particles, $a$, which in turn decay to a pair of SM particles. Several searches have been performed for $H \rightarrow aa$ in various final states [5–9].

The results presented in this Letter cover the unexplored $\gamma \gamma jj$ final state in searches for $H \rightarrow aa$, where one of the $a$ bosons decays into a pair of photons and the other decays into a pair of gluons. This final state becomes relevant in models where the fermionic decays are suppressed and the $a$ boson decays only into photons or gluons [4,10]. The ATLAS Run 1 search for $H \rightarrow aa \rightarrow \gamma \gamma jj$ [11] set a 95% CL limit $\sigma_H \times B(H \rightarrow aa \rightarrow \gamma \gamma jj) < 10^{-3} \sigma_{SM}$ for $10 < m_a < 62$ GeV, where $\sigma_{SM}$ is the production cross-section for the SM Higgs boson. There is currently no direct limit set on $B(H \rightarrow aa \rightarrow \gamma \gamma gg)$; however, in combination with $B_{BSM} < 34\%$, the $H \rightarrow aa \rightarrow \gamma \gamma jj$ result sets an indirect limit on $B(H \rightarrow aa \rightarrow \gamma \gamma gg)$ to less than ~4%. Assuming the same ratio of photon and gluon couplings to the $a$ boson as to the SM Higgs boson, the $H \rightarrow aa \rightarrow \gamma \gamma jj$ decay occurs very rarely relative to the $H \rightarrow aa \rightarrow \gamma \gamma gg$ decay (a typical value for the ratio $B(H \rightarrow aa \rightarrow \gamma \gamma jj)/B(H \rightarrow aa \rightarrow \gamma \gamma gg)$ is $3.8 \times 10^{-3}$ [10]) making $H \rightarrow aa \rightarrow \gamma \gamma jj$ an excellent unexplored final state for probing these fermion-suppressed coupling models. The branching ratio for $a \rightarrow \gamma \gamma$ can be enhanced in some scenarios. The two searches are therefore complementary, where the $H \rightarrow aa \rightarrow \gamma \gamma jj$ final state is more sensitive to photon couplings with the new physics sector similar to the photon coupling to the SM Higgs boson, while the $H \rightarrow aa \rightarrow \gamma \gamma jj$ final state is more sensitive to scenarios with enhanced photon couplings. In addition, the $H \rightarrow aa \rightarrow \gamma \gamma jj$ final state can probe models inaccessible by the $H \rightarrow aa \rightarrow \gamma \gamma jj$ final state, for example $H \rightarrow a' a' \rightarrow \gamma \gamma jj$ where the $a$ and $a'$ are both (pseudo)scalar particles with similar masses with primary decays to photons and gluons, respectively.

Reference [10] shows that the search for $H \rightarrow \gamma \gamma gg$, where the Higgs boson is produced in association with a vector boson which

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decays leptonically, would require approximately 300 fb\(^{-1}\) of LHC data in order to be sensitive to branching ratios less than 4\%. The gluon–gluon fusion (ggF) production mode has a larger cross-section, but is overwhelmed by the \(γγ\) + multi-jet background. The strategy described in this Letter consists in selecting events where vector-boson fusion (VBF) is the dominant Higgs boson production mode. Even though the production rate is lower than that for the ggF mode, the characteristic topology of the jets produced in association with the Higgs boson enables more effective suppression of the background.

2. Data and simulation

The search presented in this Letter is based on the 36.7 fb\(^{-1}\) dataset of proton–proton collisions recorded by the ATLAS experiment at the LHC at \(\sqrt{s} = 13\) TeV during 2015 and 2016. The ATLAS detector [12] comprises an inner detector in a 2 T axial magnetic field, for tracking charged particles and a precise localisation of the interaction vertex, a finely segmented calorimeter, a muon spectrometer and a two-level trigger [13] that accepts events at a rate of about 1 kHz for data storage. Monte Carlo (MC) event generators were used to simulate the \(H \rightarrow aa \rightarrow γγgg\) signal. Signal samples for the ggF and VBF processes were generated at next-to-leading order using POWHEG-Box [14–16] interfaced with \textsc{Pythia} [17] for parton showering and hadronisation using the A2ZLO set of tuned parameters set 18 and the CT10 parton distribution function (PDF) set 19. Samples were generated in the \(m_\text{Z}\) range\(^2\) 20 GeV < \(m_\text{Z}\) < 60 GeV, assuming the a boson to be a (pseudo)scalar. All MC event samples were processed through a detailed simulation [20] of the ATLAS detector based on \textsc{geant4} [21], and contributions from additional pp interactions (pile-up), simulated using \textsc{Pythia} and the MSTW2008LO PDF set [22], were overlaid onto the hard-scatter events.

3. Selection criteria

Events are selected by two diphoton triggers. One trigger path requires the presence in the electromagnetic (EM) calorimeter of two clusters of energy deposits with transverse energy\(^2\) above 35 GeV and 25 GeV for the leading (highest transverse energy) and sub-leading (second-highest transverse energy) clusters, respectively. In the high-level trigger the shape of the energy deposit in both clusters is required to be loosely consistent with that expected from an EM shower initiated by a photon. The other trigger path requires the presence of two clusters with transverse energy above 22 GeV. In order to suppress the additional rate due to the lower transverse energy threshold, the shape requirements for the energy deposits are more stringent.

The photon candidates are reconstructed from the clusters of energy deposits in the EM calorimeter within the range |\(η\)| < 2.37. The energies of the clusters are calibrated to account for energy losses upstream of the calorimeter and for energy leakage outside the cluster, as well as other effects due to the detector geometry and response. The calibration is refined by applying \(η\)-dependent correction factors of the order of ±1\%, derived from \(Z \rightarrow ee\) events [23]. As in the trigger selection, photon candidates are required to satisfy a set of identification criteria based on the shape

\(^{1}\) The diphoton triggers considered for this search do not have acceptance for the lower mass range (\(m_\text{Z} < 20\) GeV), where the two photons are collimated.

\(^{2}\) ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upward. Cylindrical coordinates (r, φ) are used in the transverse plane, φ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as \(η = −\ln \tan(θ/2)\).
4. Background estimation

The $\gamma\gamma+\text{multi-jet}$ background consists of multi-jet events with two reconstructed photon candidates, originating from isolated EM radiation or from jets. A data-driven estimation based on two-dimensional sidebands is used to predict the background yields. The method consists of using two uncorrelated observables to define four regions labelled A, B, C and D.

The first axis of the A/B/C/D plane separates events in regions C and D with both photons passing the Tight requirement from events in regions A and B with at most one photon passing the Tight requirement and at least one passing the Loose but not the Tight requirement. These regions are referred to respectively as Tight–Tight (C and D) and Tight–Loose (A and B).

The second axis separates events in regions B and D, satisfying $|m_{jj} - m_{\gamma\gamma}| < x_b$, from events in regions A and C, satisfying $|m_{jj} - m_{\gamma\gamma}| > x_b$. The value $x_b$ depends on the $m_{\gamma\gamma}$ regime $R$ to account for the degradation in resolution at higher mass. For $H \rightarrow aa \rightarrow \gamma\gamma gg$ signal events, the $a$ boson candidates have similar masses, the difference $|m_{jj} - m_{\gamma\gamma}|$ tends to be smaller than in the background, as shown in Fig. 1(c). The signal events that lie outside of the range $|m_{jj} - m_{\gamma\gamma}| < x_b$ are due to poor $m_{jj}$ resolution or to incorrect assignment of the jets corresponding to the gluons originating from the $a$ boson decay. Specific $x_b$ values are given in Table 1. In each $m_{\gamma\gamma}$ regime, the boundary for $|m_{jj} - m_{\gamma\gamma}|$ is 0.4 times the central $m_{\gamma\gamma}$ value. An exception is made for the lowest $m_{\gamma\gamma}$ regime, where $x_b$ is larger in order to increase the signal efficiency.

Region D is expected to contain the highest contribution of signal. In this region, 60% of the signal events are produced in the VBF mode and the remaining 40% in the ggF mode. Assuming no correlation in the background events between the two observables used to define the A/B/C/D regions, the number of background events in the signal region D ($N_{D}^{bkg}$) is related to the number of background events in the control regions A, B and C, denoted by $N_{A}^{bkg}$, $N_{B}^{bkg}$ and $N_{C}^{bkg}$, respectively, by the formula

$$N_{D}^{bkg} = \frac{N_{B}^{bkg} N_{C}^{bkg}}{N_{A}^{bkg}}. \quad (1)$$

In the following, the difference between the prediction $N_{D}^{bkg}$ and the actual background yield in region D is referred to as non-closure. The non-closure results from residual correlations between the two observables used to define the A/B/C/D regions, and the uncertainty accounting for this effect is referred to as closure uncertainty. In order to quantify the non-closure, the data-driven estimation as described above is performed with the expectation that the requirement on $m_{\gamma\gamma}$ is inverted. For each $m_{\gamma\gamma}$ regime, the closure uncertainty is defined to be the central value of the non-closure if it is found to be significant ($>1\sigma$) in comparison with its statistical uncertainty; otherwise, the statistical uncertainty of its estimate is used.
Table 2

<table>
<thead>
<tr>
<th>m_{Z} [GeV]</th>
<th>( m_{\gamma \gamma} ) regime</th>
<th>Efficiency (( \times 10^{-3} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>1</td>
<td>0.60^{+0.14}_{-0.14}</td>
<td>1.2 \pm 0.4</td>
</tr>
<tr>
<td>25</td>
<td>0.67^{+0.27}_{-0.23}</td>
<td>2.6 \pm 0.5</td>
</tr>
<tr>
<td>25</td>
<td>0.67^{+0.27}_{-0.23}</td>
<td>2.6 \pm 0.5</td>
</tr>
<tr>
<td>30</td>
<td>1.22 \pm 0.34</td>
<td>3.3 \pm 0.9</td>
</tr>
<tr>
<td>35</td>
<td>1.8 \pm 1.1</td>
<td>2.7 \pm 1.2</td>
</tr>
<tr>
<td>35</td>
<td>0.53^{+0.25}_{-0.24}</td>
<td>4.1 \pm 1.2</td>
</tr>
<tr>
<td>40</td>
<td>1.2 \pm 0.9</td>
<td>3.3 \pm 1.0</td>
</tr>
<tr>
<td>45</td>
<td>2.5 \pm 1.0</td>
<td>4.1 \pm 1.3</td>
</tr>
<tr>
<td>45</td>
<td>2.2 \pm 0.9</td>
<td>4.4 \pm 1.4</td>
</tr>
<tr>
<td>50</td>
<td>0.93 \pm 0.30</td>
<td>4.4 \pm 1.2</td>
</tr>
<tr>
<td>55</td>
<td>0.37 \pm 0.11</td>
<td>3.3 \pm 0.9</td>
</tr>
<tr>
<td>55</td>
<td>0.23 \pm 0.16</td>
<td>3.6 \pm 1.0</td>
</tr>
<tr>
<td>60</td>
<td>0.77^{+0.12}_{-0.10}</td>
<td>3.9 \pm 1.0</td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>( m_{\gamma \gamma} ) regime</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Relative closure uncert.</th>
<th>Predicted background yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>4</td>
<td>28</td>
<td>4</td>
<td>0.50</td>
<td>6.9^{+2}_{-3}</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>6</td>
<td>34</td>
<td>15</td>
<td>0.32</td>
<td>8.5^{+4}_{-4}</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>16</td>
<td>29</td>
<td>26</td>
<td>0.20</td>
<td>27^{+12}_{-12}</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>12</td>
<td>19</td>
<td>38</td>
<td>0.21</td>
<td>27^{+12}_{-12}</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>20</td>
<td>20</td>
<td>36</td>
<td>0.20</td>
<td>66^{+56}_{-28}</td>
</tr>
</tbody>
</table>

5. Results

The efficiency of the event selection for the inclusive \( pp \rightarrow H \rightarrow aa \rightarrow \gamma \gamma gg \) signal in each of the A/B/C/D regions is shown in Table 2, assuming the SM Higgs boson production cross-section and kinematics, in each of the A/B/C/D regions, for different \( m_{Z} \) mass hypotheses. For each \( m_{Z} \) value, all \( m_{\gamma \gamma} \) regimes in which there is no significant signal acceptance loss due to the \( m_{\gamma \gamma} \) requirement are shown.

The low number of observed events is the dominant source of uncertainty for this search. The second largest uncertainty is due to the closure uncertainty, also statistical in nature. Other sources of systematic uncertainty only affect the overall signal normalisation and the amount of signal contamination in control regions A, B and C. Dominant sources of experimental systematic uncertainty arise from the calibration and resolution of the energy of the jets [32,33]. Uncertainties associated with the photon energy calibration and resolution [23], as well as the photon identification and isolation efficiencies [24], are found to be negligible. Uncertainties associated with the estimation of the integrated luminosity and the simulation of pile-up interactions (Lumi and Pile-up) are evaluated by varying the choice of scales used in the generator program and assuming the SM Higgs boson production [34]. It is found to be similar in size to the experimental systematic uncertainty.

Nuisance parameters corresponding to each source of uncertainty are included in the profile likelihood with Gaussian constraints. Their effects on the estimated number of signal events \( \mu_{S} \) are studied using Asimov [35] pseudo-datasets generated for an expected signal corresponding to the 95% CL upper limit obtained in this search and using the values of the background parameters marginalised in the likelihood fit to data which assumes no signal. Table 4 summarises the impact of each source of uncertainty varied by \( \pm 1\sigma \) on the maximum-likelihood estimate for \( \mu_{S} \) in each of the \( m_{\gamma \gamma} \) regimes for an illustrative \( m_{Z} \) hypothesis. The statistical uncertainty is the largest one for all regimes. The best-fit values of the parameters of the likelihood function are given in Table 5. The probability that the data are compatible with the background-only hypothesis is computed for each \( m_{\gamma \gamma} \) regime and no significant excess is observed. The smallest local \( p \)-value, obtained for the \( m_{\gamma \gamma} \) regime 2 (\( m_{\gamma \gamma} \approx 30 \text{ GeV} \)), is of the order of 4%. No significant excess is observed, and an upper limit is derived at 95% CL. The expected and observed exclusion limits on \( \mu_{S} \) are given in Table 6. This is related to the limit on the \( pp \rightarrow H \rightarrow aa \rightarrow \gamma \gamma gg \) cross-section by appropriately normalising to the measured total integrated luminosity and selection efficiencies relative to the inclusive signal production obtained from the ggF and VBF MC samples (Table 2). The limit is also expressed relative to the SM cross-section for the Higgs boson, shown in Fig. 2. Within a \( m_{\gamma \gamma} \) analysis regime, limits are interpolated linearly in between simulated \( m_{\gamma \gamma} \) values. Finally, for each mass point, the \( m_{\gamma \gamma} \) regime that yields the best expected limit is used to provide the observed exclusion limit. The limit is calculated using a frequentist CL\_s calculation [36].

from MC simulation and is varied coherently with \( \mu_{S} \) in the likelihood fit.
Table 4
Maximum fractional impact on the fitted $\mu_S$ from sources of systematic uncertainty estimated using Asimov datasets. The signal injected in the Asimov datasets corresponds to the observed upper limit quoted in Table 6.

<table>
<thead>
<tr>
<th>Source of uncert.</th>
<th>$m_{T\gamma}$ regime</th>
<th>$m_\gamma$ = 20 GeV</th>
<th>$m_\gamma$ = 30 GeV</th>
<th>$m_\gamma$ = 40 GeV</th>
<th>$m_\gamma$ = 50 GeV</th>
<th>$m_\gamma$ = 60 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical</td>
<td>0.73</td>
<td>0.51</td>
<td>0.89</td>
<td>1.13</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>Closure</td>
<td>0.44</td>
<td>0.27</td>
<td>0.39</td>
<td>0.64</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>Modelling</td>
<td>0.35</td>
<td>0.34</td>
<td>0.46</td>
<td>0.42</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>Jet</td>
<td>0.58</td>
<td>0.38</td>
<td>0.25</td>
<td>0.90</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>Photon</td>
<td>0.06</td>
<td>0.05</td>
<td>0.10</td>
<td>0.12</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Lumi and Pile-up</td>
<td>0.06</td>
<td>0.04</td>
<td>0.27</td>
<td>0.14</td>
<td>0.32</td>
<td></td>
</tr>
</tbody>
</table>

6. Conclusions

In summary, a search for exotic decays of the Higgs boson into a pair of new (pseudo)scalar particles, $H \to aa$, in final states with two photons and two jets is conducted using 36.7 fb$^{-1}$ of $pp$ collisions at $\sqrt{s} = 13$ TeV recorded with the ATLAS detector at the LHC. The search for $H \to aa \to \gamma\gamma gg$ is performed in the mass range $20 < m_a < 60$ GeV and with additional jet requirements to enhance VBF-produced signal while suppressing the $\gamma\gamma$+jets background. No significant excess of data is observed relative to the SM predictions. An upper limit is set for the product of the production cross-section for $pp \to H$ and the branching ratio for the decay $H \to aa \to \gamma\gamma gg$. The upper limit ranges from 3.1 pb to 9.0 pb depending on $m_a$, and is mostly driven by the statistical uncertainties. These results complement the previous upper limit on $H \to aa \to \gamma\gamma\gamma\gamma$ and further constrains the BSM parameter space for exotic decays of the Higgs boson.

Table 5
Maximum-likelihood fit values for each of the free parameters of the likelihood function in each $m_{T\gamma}$ regime for a relevant signal $m_\gamma$ hypothesis. The estimated uncertainties in the fit parameters assume that the likelihood function is parabolic around the minimum of the fit.

<table>
<thead>
<tr>
<th>$m_{T\gamma}$ regime</th>
<th>$m_\gamma$ [GeV]</th>
<th>$\mu_S$</th>
<th>$\mu_{bkg}$</th>
<th>$t_b$</th>
<th>$t_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>$-7 \pm 18$</td>
<td>$11 \pm 17$</td>
<td>0.5 $\pm 0.4$</td>
<td>2.9 $\pm 3.1$</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>$8 \pm 8$</td>
<td>$7 \pm 0.6$</td>
<td>0.68 $\pm 0.32$</td>
<td>4.3 $\pm 3.1$</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>$30 \pm 80$</td>
<td>$60 \pm 70$</td>
<td>0.35 $\pm 0.19$</td>
<td>0.67 $\pm 0.33$</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>$22 \pm 28$</td>
<td>$16 \pm 23$</td>
<td>0.5 $\pm 0.4$</td>
<td>0.9 $\pm 1.0$</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>$-290 \pm 260$</td>
<td>$340 \pm 340$</td>
<td>0.21 $\pm 0.05$</td>
<td>0.24 $\pm 0.05$</td>
</tr>
</tbody>
</table>

Fig. 2. The observed (solid line) and expected (dashed line) 95% CL exclusion upper limit on the $pp \to H \to aa \to \gamma\gamma gg$ cross-section times branching ratio as a function of $m_\gamma$, normalised to the SM inclusive $pp \to H$ cross-section [31]. The vertical lines indicate the boundaries between the different $m_{T\gamma}$ analysis regimes. At the boundaries, the $m_{T\gamma}$ regime that yields the best expected limit is used to provide the observed exclusion limit (filled circles); the observed limit provided by the regime that yields the worse limit is also indicated (empty circles).

Table 6
Observed (expected) upper limits at the 95% CL, for each of the $m_\gamma$ values considered in the search. In each case, the $m_{T\gamma}$ regime used to calculate the limits is also indicated. The limits reflect both the statistical and systematic sources of uncertainty in the fit, and the $\pm 1\sigma$ widths of the expected limit distributions are also indicated.

<table>
<thead>
<tr>
<th>$m_{T\gamma}$ regime</th>
<th>$m_\gamma$ [GeV]</th>
<th>$\mu_S$</th>
<th>$\sigma_H \times B(H \to aa \to \gamma\gamma gg)$ [pb]</th>
<th>$\sigma_{obs} \times B(H \to aa \to \gamma\gamma gg)$ [pb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>$10.4^{+4.0}_{-2.5}$</td>
<td>$4.8^{+6.1}_{-3.1}$</td>
<td>$0.086^{+0.022}_{-0.025}$</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>$10.4^{+9.3}_{-2.4}$</td>
<td>$1.9^{+2.0}_{-0.6}$</td>
<td>$0.034^{+0.036}_{-0.008}$</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>$25^{+5.3}_{-2.6}$</td>
<td>$5.1^{+4.7}_{-1.1}$</td>
<td>$0.092^{+0.084}_{-0.019}$</td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>$26^{+4.4}_{-1.9}$</td>
<td>$3.1^{+2.6}_{-0.7}$</td>
<td>$0.056^{+0.049}_{-0.012}$</td>
</tr>
<tr>
<td>5</td>
<td>40</td>
<td>$36^{+3.9}_{-1.6}$</td>
<td>$2.7^{+2.2}_{-0.9}$</td>
<td>$0.049^{+0.040}_{-0.011}$</td>
</tr>
<tr>
<td>6</td>
<td>45</td>
<td>$41^{+3.1}_{-1.3}$</td>
<td>$3.2^{+4.0}_{-1.2}$</td>
<td>$0.058^{+0.073}_{-0.025}$</td>
</tr>
<tr>
<td>7</td>
<td>50</td>
<td>$45^{+3.6}_{-1.8}$</td>
<td>$6.3^{+7.5}_{-2.5}$</td>
<td>$0.113^{+0.134}_{-0.020}$</td>
</tr>
<tr>
<td>8</td>
<td>55</td>
<td>$45^{+3.3}_{-1.7}$</td>
<td>$9.2^{+8.4}_{-2.1}$</td>
<td>$0.166^{+0.152}_{-0.036}$</td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>$50^{+4.4}_{-2.0}$</td>
<td>$9.0^{+8.8}_{-2.0}$</td>
<td>$0.162^{+0.159}_{-0.027}$</td>
</tr>
<tr>
<td>10</td>
<td>65</td>
<td>$55^{+4.1}_{-2.1}$</td>
<td>$9.7^{+9.1}_{-2.2}$</td>
<td>$0.173^{+0.163}_{-0.027}$</td>
</tr>
<tr>
<td>11</td>
<td>70</td>
<td>$60^{+4.4}_{-2.2}$</td>
<td>$5.5^{+6.8}_{-2.1}$</td>
<td>$0.10^{+0.12}_{-0.04}$</td>
</tr>
<tr>
<td>12</td>
<td>75</td>
<td>$65^{+4.7}_{-2.4}$</td>
<td>$8.0^{+9.5}_{-3.6}$</td>
<td>$0.14^{+0.17}_{-0.05}$</td>
</tr>
</tbody>
</table>
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